Volume I

Final
Basis of Design Report

Lower Fox River and Green Bay Site

Brown, Outagamie, and Winnebago Counties, Wisconsin

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minor unaccounted change in volume over the 39 miles, supporting the case of limited groundwater discharge. For the same study, an inspection of a dolomite quarry in Kaukauna, approximately 100 feet from the Lower Fox River, revealed limited groundwater discharge into the quarry from several hundred feet of dolomite, further supporting the case of limited ground water movement through this formation and therefore no source to discharge to the river (Conlin 2002, Krohelski 2002).

Although the majority of the Upper Aquifer is comprised of relatively low permeability material, lenses of sand and gravel could potentially produce locally significant discharges to the Lower Fox River where such lenses intersect the river bed. However, detailed sampling and analysis of the river during the 2004 and 2005 RD investigations did not reveal any such lenses. Groundwater flow is discussed in more detail in Section 5.

2.2.4.2 Surface Water Hydrology

The Lower Fox River flows northeast for 39 miles from Lake Winnebago, the largest inland lake in Wisconsin, to Green Bay (Figure 1-1). The Fox River is the largest tributary to Green Bay, draining approximately 6,330 square miles with a mean annual discharge of 5,000 cubic feet per second (cfs) (USGS 1998). From Lake Winnebago to Green Bay, the river drops 168 feet over a series of locks and dams, as described above.

The Lower Fox River flows across a relatively low permeability substrate comprised of Quaternary deposits of lacustrine clay, silt, and glacial till throughout much of its length. In addition, bedrock exposures of the Sinnipee dolomite crop out in parts of the river bed. Groundwater discharge to the river is therefore limited.

Rainfall-Runoff. In a typical year, Green Bay receives 28.8 inches of total precipitation. The month of April generally exhibits the highest river flows, due to winter snow melt combined with spring rain. The late summer months of August and September generally exhibit the lowest flows (Table 2-4; Retec 2002c).

Lower Fox River Flows. The U.S. Geological Society (USGS) has monitored stream flow in the Lower Fox River at several different gaging stations within the watershed. By far the longest stream gaging record is at the Rapide Croche Dam in Wrightstown in the lower reach of OU 2 (#04084500). Flow rates at Wrightstown have been recorded continuously since 1917 providing a long term data set for determination of flow recurrence intervals (http://waterdata.usgs.gov/wi/nwis/rt; WDNR 2000). Summary statistics of Lower Fox River discharge data for the Rapide Croche Dam station are summarized in Table 2-4.

Flow rates during a typical year vary from 30 to 280 cubic meters per second (m^3/s; 1,060 to 9,900 cubic feet per second [cfs]). The highest discharge typically occurs during the spring months of

March through June, when the river is recharged by snowmelt and spring rains. The highest flow rate recorded on the river in the past 80 years is approximately 650 m^3/s (23,000 cfs) and corresponds to a 50 year recurrence interval, as summarized in Table 2-5.

In addition to the gage at the Rapide Croche Dam, the USGS has operated an acoustic velocimeter (AVM) in OU 4, about 0.8 miles upstream from the river mouth, since 1989 (Table 2-4). The average flow statistics near the mouth of the river are similar to those at Rapide Croche Dam, consistent with similar watershed areas draining to the two gages (drainage area increases by only 5 percent between the two gaging stations). There is little additional surface water recharge, and as discussed above also little gain or loss due to groundwater within this lower reach of the river. Seiche effects evident at the mouth gage are discussed below.

Table 2-4. Lower Fox River Discharge Data

Summary Statistics:

	Rapide Croche 1918-1997		Fox River Mouth 1989-1999	
	Discharge (m^3/s)	Discharge (cfs)	Discharge (m^3/s)	Discharge (cfs)
Daily Average	122	4,314	141	4,999
Daily Maximum	680	24,000	957	33,800
Daily Minimum	4	138	-92	-3,260
Monthly Maximum	206	7,286	215	7,580
Monthly Minimum	74	2,609	92	3,256
10th Percentile	--	--	54	1,920
50th Percentile	--	--	114	4,040
90th Percentile	--	--	272	9,610

Monthly Statistics:

	Rapide Croche 1918-1997			
	Average (m^3/s)	Average (cfs)	Minimum (m^3/s)	Maximum (m^3/s)
January	116	4,082	31	269
February	117	4,126	30	340
March	146	5,156	25	603
April	206	7,286	22	680
May	171	6,048	23	669
June	137	4,821	17	603
July	96	3,372	18	530
August	74	2,609	4	419
September	81	2,872	8	510
October	94	3,315	6	516
November	116	4,084	15	445
December	115	4,043	32	363

Table 2-5. Summary of Lower Fox River Flow Rates at Rapide Croche Dam

Recurrence Interval (years)	Flow (m^3/s)	Flow (cfs)
2	360	12,700
5	481	17,000
10	544	19,200
25	612	21,600
50	651	23,000
100	685	24,200

Lower Fox River Velocities. River velocity provides a key control of sediment deposition and erosion processes in the Lower Fox River, and is also a critical parameter for evaluation of armored cap elements of the ROD and Optimized Remedies (Palermo et al. 1998a & 1998b, Johnson Co. 2001). The USGS and Sea Engineering Inc. (SEI 2004 & 2005) recently completed a study of the hydrodynamics in OUs 3 and 4 under various flow conditions. The study included the collection of vertical velocity profiles by the USGS at 30 locations in OU 4 during four events spanning a range from low (100 m^3/s [3,500 ft^3/s]; seiche dominated) to high (400-450 m^3/s [14,100 to 15,900 cfs]; flood dominated) river flow conditions. Vertical velocity profiles were also measured by the USGS at 33 locations in OU 3 during a single moderate flow event (250 m^3/s [8,800 cfs]). SEI used the field data collected by USGS to develop and calibrate a 2-dimensional hydrodynamic model to predict bottom shear stresses in both OU 3 and OU 4. The SEI reports for OUs 3 and 4 are provided in Appendix D.

Average river velocities have previously been estimated for various sub-reaches of OU 3 and OU 4 based on a consideration of the combined effects of flood flows and seiche currents. River velocities have been estimated for 10-year and 100-year peak flood events based on analyses of USGS gaging records and river cross-section data (WDNR 1995). The average annual river velocity in OU 3 is approximately 0.40 feet per second (fps), and the average river velocity in OU 4 is roughly 0.26 fps. These average velocities are within the range of values where silt- and sand-sized particles will settle, and is consistent with the presence of extensive deposits of recent fine-grained sediments observed in these lower reaches of the river. As discussed in Section 5, more detailed evaluations of river velocity under the Optimized Remedy were performed for this BODR using the SEI models.

Seiche Events. Green Bay is subject to seiche events—short-term changes in water level elevation caused by northeasterly winds or barometric pressure differentials that cause water build up in the southern end of the bay. Seiche events can increase water levels near the mouth of the river by a few inches to a few feet when combined with storm conditions. Historical stage records for the Fox River indicate that seiches typically occur twice daily with a return period of approximately 11 hours. This can cause a short-term reversal of flow direction in OU 4 and induce rapid mixing of bay and river waters (Smith et al. 1988, Gailani et al. 1991).

Variations in flow caused by seiche effects are largest near the mouth of the Lower Fox River at the OU 4 / OU 5 boundary, and progressively decrease for approximately 7 miles upstream to the De Pere Dam. Reversing currents associated with the seiche effects has resulted in instantaneous peak discharges at the river mouth as high as 957 m^3/sec (33,800 cfs). As discussed in Section 5, worst-case seiche effects are considered in the cap armor design for capping elements of the ROD Remedy (e.g., certain shoreline areas), and the Optimized Remedy.

Green Bay Water Level Elevations. The water level elevation in Green Bay is controlled by water levels in the Lake Michigan-Huron basin. The long-term average (LTA) elevation for the lake basin between 1918 and the December 2003 is 578.94 feet IGLD 1985, as shown on the hydrograph on Figure 2-4. This hydrograph also indicates that the Lake Michigan-Huron basin experiences extended periods of extremely low water (below the NOAA low water datum of 577.5 feet IGLD 85) approximately every 30 years. The historical low and high lake water levels since 1918 are 576.05 feet (March 1964) and 582.35 feet (October 1986), respectively (USACE 2004). Recent lake levels have been below LTA elevations, due to lower than average snowmelt runoff and several consecutive warm winters.

Figure 2-5 presents the hydrograph of water elevations measured at the mouth of the Fox River in Green Bay (NOAA Station 9087079) for the period 1979 through 2005. Short-term variability in water levels is evident in the Figure 2-5 plot. Consideration of both short- and long-term temporal changes in water levels is an important element of cap design, and further discussion of seasonal probabilities of water and ice elevations in the river is provided in Section 5 of this BODR.

2.2.5 Geotechnical Conditions

The geotechnical properties used for this design were evaluated during two separate RD field investigations conducted by the Shaw/Anchor team (Shaw/Anchor 2004 and 2005). Numerous other studies were conducted prior to the Shaw/Anchor investigations (since 1989), but the results of these investigations were used only to help guide the Shaw/Anchor sampling since historical data contain limitations including (1) lack of subsurface (below 10 cm) samples; (2) cores were collected by different investigators, using different field methods, and years apart in time; and (3) cores from different studies were likely subjected to different degrees of sampling-induced compaction. Therefore, the sampling scheme described in the SAP (Shaw/Anchor 2004 and 2005) was intended to provide a stand-alone data set to support RD.

The following sections present a summary of the data collected during the Shaw/Anchor RD sampling investigations. The data presented in this section is intended to provide a representative summary of OUs 2-5 as a whole and not specifically those sediments targeted for dredging. Sections 3 and 5 discuss the geotechnical properties of those sediments targeted for dredging under the ROD and Optimized Remedies, respectively. All geotechnical data is presented in the RD Data Report (Shaw/Anchor 2006a).

2.2.5.1 Grain Size

Grain size data were collected throughout OUs 2 to 5 of the Lower Fox River and Green Bay, including the Cat Island area of OU 5. In total, approximately 350 grain distribution tests (ASTM D-422) were performed on samples collected from between 0 and 9 feet deep (below the mudline).